Loran Data Channel Communications using 9th Pulse Modulation

Version 1.2

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Last Modified: 20060803

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Overview and Purpose

It is desired to add to the functionality of the current LORAN-C signal. Desired capabilities include the transmission of absolute time, and Differential LORAN corrections for maritime and timing users, anomalous propagation (early skywave) warnings, and LDC system information for high-integrity applications. The USCG is in the process of evaluating an implementation of such a communications channel, named the Loran Data Channel (LDC), for use with the current LORAN-C signal. The Loran Data Channel (LDC) is currently in the engineering development phase. The purposes of this document are:

1) To communicate the ***current*** method of modulation and transmission of LDC from selected Loran Stations.
2) To describe any known ***future*** changes and other modifications under consideration.

Accordingly, this document should be read in it's entirety to best understand the state of LDC research. This document contains four (4) sections:

1) Overview and Purpose: This section.

2) Ninth-Pulse Modulation: Provides general information on the modulation scheme.

3) Current Description of Transmitted LDC Signal: Describes the transmission scheme currently in use. This section should be reviewed before attempting to demodulate the LDC signal. Expect the content of this section to change with future versions of this document.

4) Future Changes: Describes any known future changes or any changes under consideration.

Ninth-Pulse Modulation

This modulation scheme was chosen for its negligible impact on the current operational LORAN-C signal, and its facility for cancellation of cross-rate interference. Here, an additional pulse is inserted in time following the eighth pulse of the LORAN pulse group. Thirty-two state Pulse-position modulation is used to change the time delay of this pulse from the zero-symbol offset. In this manner, the data transfer rate is five bits per group repetition interval (GRI). In figure 1, the modulated pulse is darkened to show the relationship to the navigation group of eight pulses and master-rate pulse.

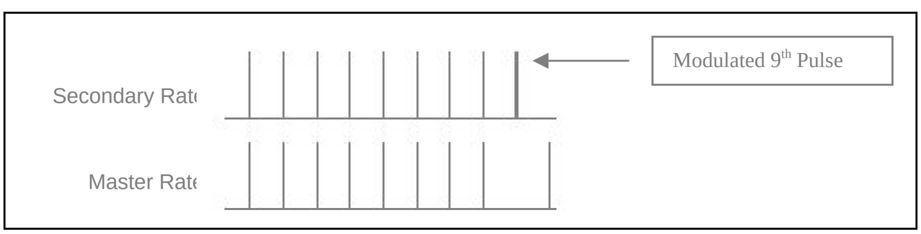

Figure 1: Location of 9th Pulse within Loran Group.

The phase code of the 9th pulse is the same as the phase code of the last navigation pulse.

Group	Master		Secondary	
A	+ + - - + - + -	+	+ + + + + - - +	+
B	+ - - + + + + +	-	+ - + - + + - -	-

NOTE: (1) Shaded Area = Phase Coding of Modulated (9th) Pulse

Figure 2: Phase Coding of Loran Pulses

The zero-symbol offset is 1000 microseconds after the 8th navigation pulse. The remaining 31 symbols are positioned in time a specific number of microseconds later in relationship to the zero symbol. The ideal delays are given by the formula:

$$d_i = 1.25 mod(i,8) + 50.625 floor(i/8)$$

The actual delays are the ideal values shifted to coincide with the ticks of a 5MHz clock. Table 1 lists the symbol i and corresponding time delay d_i with respect to the zero symbol.

i = [0,7]		*i = [8,15]*		*i = [16,23]*		*i = [24,31]*	
0	0.0	**8**	50.6	**16**	101.2	**24**	151.8
1	1.2	**9**	51.8	**17**	102.6	**25**	153.2
2	2.6	**10**	53.2	**18**	103.8	**26**	154.4
3	3.8	**11**	54.4	**19**	105.0	**27**	155.6
4	5.0	**12**	55.6	**20**	106.2	**28**	156.8
5	6.2	**13**	56.8	**21**	107.6	**29**	158.2
6	7.6	**14**	58.2	**22**	108.8	**30**	159.4
7	8.8	**15**	59.4	**23**	110.0	**31**	160.6

Table 1: Symbol Delays from zero-symbol offset (μs)

<u>Messages:</u>

All messages are 120 bits in length and consist of 3 components: a 4-bit type, a 41-bit payload, and a 75-bit parity component. The messages are transmitted 5bits/GRI. The time length of the messages is 24 GRI (maximum of approximately 2.4 seconds).

Section	Type	Payload	Parity
Length (bits)	4	41	75
Bit assignment	0…3	4…44	45…119

<u>Type Component:</u>

Table 3 below is the most recent list of proposed message types. All message types may not currently be in use. For information on content of broadcasted signals, see the section entitled “Current Schema”

Number	Type code	Description
0	0000	Reference Site Phase Correction
1	0001	Almanac (further divided into sub-messages)
2	0010	Message for government use only
3-14	0011 thru 1110	undefined
15	1111	Station Identification and Time-of-Day

Payload Component:

Note: For bit-level details on the message payloads, see the message payload tables later in this document.

Type 0: Differential Phase Correction:
This message contains the ASF Phase correction data from an Differential Reference Sites. The purpose of this message is to mitigate the temporal component of the ASF. The correction is given relative to a published nominal value. It is expressed as a 2's compliment number (2ns resolution). The total correction used for navigation is the sum o the transmitted correction and offsets determined by calibration. A value of -512 (1000000000b) indicates that the signal should not be used.

Type 1: Almanac:
This message contains system-wide almanac data that is useful in high-integrity receiver systems. It is used to pass updated system information to the end user. This message is divided into sub-types according to the information content.

- *Sub-type 0:* Reference Station List: This message is used to communicate which reference station corrections are being sent from which LORSTA, and to indicate the status of the LDC broadcast from other LORSTAs.

- *Sub-type 1:* Reference Station Latitude: This message contains the latitude of a reference station whose corrections are being sent from this transmitter. A useful formula is the conversion from a 26-bit binary to decimal latitude:

  $$LAT_{decimal} = LAT_{binary} \cdot 180^{o} / \left(2^{26}\right) = \left(2.682209015 \times 10^{-6}\right) LAT_{binary}$$

  where LAT_{binary} is the latitude expressed in a 26-bit binary, 2's compliment integer.

- *Sub-type 2:* Reference Station Longitude: This message contains the longitude of a reference station whose corrections are being sent from this transmitter. A useful formula is the conversion from a 26-bit binary to decimal longitude:

  $$LON_{decimal} = LON_{binary} \cdot 360^{o} / \left(2^{26}\right) = \left(5.364418030 \times 10^{-6}\right) LON_{binary}$$

  where LON_{binary} is the longitude expressed in a 26-bit binary, 2's compliment integer.

- *Sub-types 3-6*: Reference Station Correction List: These messages contain the signal ID codes for the corrections from a particular reference station. Sub-type 3 contains the codes for signals (1-3), sub-type 4 contains the codes for signals (4-6), etc.

- *Sub-types 7-9*: Reference Station Nominal List: These messages contain the nominal ASF values that a particular differential reference site associates with the corrections it calculates. Sub-type 7 contains the nominal values for signals (1-3), sub-type 8 contains the nominal values for signals (4-6), etc.

Type 3: Reserved for Government Use:
This message is for government use only. The data is not meant to be used for navigational or timing purposes and should be ignored.

Type 15: Time of Day: This message contains the absolute time, expressed as the number of seconds since 000000Z 01 JAN 1958. The number of seconds T from 000000Z 01 Jan 1958 to the TOT of the first pulse of the first GRI of this message is given by:

$$T = 24(GRI)(MEC) + ED$$

where GRI, is the group repetition interval in seconds, MEC is the current message epoch count, and ED is the published emission delay of the LORSTA sending this message.

Parity Component:

Reed-Solomon Coding

The Reed Solomon Forward Error Correcting (FEC) Code used is a RS(31,16) code which uses 5-bit symbols and has 31 code symbols of which 9 are data symbols, 15 are parity symbols and 7 are padded with zero. The primitive polynomial used is 29 hexadecimal. After the Reed Solomon parity is added, the 24 5–bit words are further encoded with a coset code to eliminate cyclic problems with the Reed Solomon code. The coset vector below is used for channel synchronization is:

Coset Vector = [0,1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23]

The coset vector simply adds 0 through 23 to the 24 words (modulo 32) after the Reed Solomon coding at the transmitter. This vector should be subtracted before Reed Solomon decoding at the receiver.

Current Description of Transmitted LDC Signal:

This section contains the most current description of the transmitted LDC signal.

> Note: It is anticipated that this section will change frequently. *To avoid confusion and facilitate detection of demodulation errors, any LDC research data collected or presented should be qualified with the version of this document that was in effect at the time the data was taken (e.g.: "This survey data was collected under LDC version X," where X is the applicable version number of this document).*

Implemented Message List:

The following messages have been implemented:

Number	Type code	Description
0	0000	Reference Site Phase Correction
15	1111	Station Identification and Time-of-Day

Any other messages have not been implemented, so the demodulation of any other message type should be attributed to a demodulation error.

LDC-enabled LORSTAs:

The following table is the current list of LDC-enabled LORAN signals:

LORSTA	Rate	Message Type(s)	Reference Site(s)
Jupiter, FL	7980Y	15	n/a
Seneca, NY	8970X	0,15	USNO
Las Cruces, NM	9610X	15	n/a

Order of Transmission:

The messages are sent in the following order: {15,0}. The first message transmitted is Type 15, which is transmitted every 13th message. The next message transmitted is Type 0, which is sent for each reference site who's corrections are sent from the particular LORSTA emitting LDC. Twelve corrections per reference site are transmitted in 6 Almanac messages (of sub-type 3 thru 6). When it is necessary to transmit the corrections from more than two reference stations (which requires more than one type-0 message), the time message (type 15) will continue to be sent every 13th message, and the update rate of the individual corrections will be less than once every 13 messages. The following table lists the order of the proposed corrections sent from LORSTA Seneca, NY:

Reference Site Name	USNO	Point Allerton
Latitude	38.92038 N	42.30250 N
Longitude	-77.06632 W	-70.91367 W
ID Code	3 (0000000011b)	4 (0000000100b)
Correction # 1	9960M	9960M
Correction # 2	9960W	9960W
Correction # 3	9960X	9960X
Correction # 4	9960Y	9960Y
Correction # 5	9960Z	9960Z
Correction # 6	7980M	5930Y
Correction # 7	7980Y	8970M
Correction # 8	7980Z	8970X
Correction # 9	5930X	7980Z
Correction # 10	8970M	5930M
Correction # 11	8970W	5930X
Correction # 12	8970X	7270W

Note on Transmissions from Single vs. Dual-Rated LORSTAs:

A modulated pulse is added to each Loran group. In dual-rate operations, each rate transmits a complete and separate message. A message is not mixed between the two rates. Users will need to demodulate only the rate that contains the desired base station data. Blanking is the standard operation during dual-rate operation. The modulated pulse is also blanked as part of the blanking of the entire Loran group. The blank symbol is not retransmitted but considered an erasure in the Reed-Solomon decoding. Blinking of a rate does not cause the modulated pulse to be blinked. In single-rate operations, there is no concern of blanking or message mixing with more than one rate. If the rate is blinked then the symbols are still transmitted as part of the Loran group.

Future Changes:

The following is a list of the changes under consideration:

1. Addition of new message types.
2. Message Type 0 (Phase Correction):
   (a) define more levels of time base quality field: have the following 4 levels: 0-15ns, 15-40ns, 40-200ns, and >200ns.
   (b) change length of age quality field from 5 to 3 bits with the following format:
   `000` = Level 1: <6 min
   `001` = Level 2: [6,20) min
   `010` = Level 3: [20min, 1hr)
   `011` = Level 4: [1,3) hr
   `100` = Level 5: [3,6) hr
   `101` = Level 6: [6,12) hr
   `110` = Level 7: [12,24) hr
   `111` = Level 8: [1,3) days
   (c) change length of ASF correction field from 10 to 11 bits. This will change the range of the ASF correction field from [-1.022,+1.022] to [-2.046,+2.046].

Table of Message Payloads

Message Type 0: Phase Correction					
Part	**Description**	**# Bits**	**Bit Assignment (Absolute)**	**Range**	**Explanation**
	Reference Station	10	4…13	[0,1023]	Reference Station Identification code: (see table for Reference Station Codes)
	Correction Number	3	14…16	[0,7]	Correction Number Identification Code **000** = Corrections 1, 2 **001** = Corrections 3,4 **010** = Corrections 5,6 **011** = Corrections 7,8 **100** = Corrections 9,10 **101** = Corrections 11,12 **110** = undefined. **111** = undefined.
	Time Base Quality	3	17…19	[0,7]	Figure indicating quality of time reference at differential station **000** = Level 1: <200 ns (rms) **001** = Level 2: [200,inf) ns (rms) **010…111** = unassigned
	Age of Correction	5	20…24	{0,1,2,3}	Figure indicating time since last correction was updated. This number is the age in minutes divided by ten and rounded down. For example: 00000b represents an age of 0-10 minutes, 00001b represents an age of 10-20 minutes, etc., and 11111b represents an age of more than 310 minutes.
	Correction 1	10	25…34	[-1.022,+1.022] µs	2's compliment number representing change from nominal correction value (2 ns resolution).
	Correction 2	10	35…44	[-1.022,+1.022] µs	2's compliment number representing change from nominal correction value (2 ns resolution).

Message Type 2: Almanac					
Part	**Description**	**# Bits**	**Bit Assignment**	**Range**	**Explanation**
	Message Sub-type	4	4…7	[0,15]	Almanac message sub-type codes: **0000** = sub-type 0: Reference Station List **0001** = sub-type 1: Reference Station Latitude **0010** = sub-type 2: Reference Station Longitude **0011** = sub-type 3: Reference Station Corrections (1-3) **0100** = sub-type 4: Reference Station Corrections (4-6) **0101** = sub-type 5: Reference Station Corrections (7-9) **0110** = sub-type 6: Reference Station Corrections (10-12) **0111** = sub-type 7: LORSTA Nominal Corrections (1-3) **1000** = sub-type 8: LORSTA Nominal Corrections (4-6) **1001** = sub-type 9: LORSTA Nominal Corrections (7-9) **1010** = sub-type 10: LORSTA Nominal Corrections (10-12) **1011...1111** = sub-types 11-15: undefined
	Sub-type payload	37	8…44	n/a	Sub-type payload. See table for Alamanac message sub-types.

Message Type 15: Time of Day					
Part	**Description**	**# Bits**	**Bit Assignment (absolute)**	**Range**	**Explanation**
	Mas/Sec ID	3	4…6	[0,7]	Master/Secondary Identification Code: **000** = Master Station of Loran Chain **001** = Victor Secondary Station **010** = Whiskey Secondary Station **011** = X-ray Secondary Station **100** = Yankee Secondary Station **101** = Zulu Secondary Station **110** = unassigned **111** = Tango (test) Station
	Leap Second Flag	1	7	{0,1}	Flag indicating leap second insertion: **0** = leap second will not be added at next published schedule, **1** = leap second will be added at next published schedule
	Leap Seconds	6	8…13	[0,63]	Number of leap seconds to apply in solution for UTC time: e.g: 010110 means 22 leap seconds. To convert LORAN time to UTC, subtract 22 leap seconds from the calculated LORAN time.
	Time	31	14…44	[97, 163] yrs	Time in seconds (resolution of 1 msg epoch). The number of seconds T from 000000Z 01 Jan 1958 to the TOT of the first pulse of the first GRI of this message is: $T = 24(GRI)(MEC) + ED$, where: GRI, is the group repetition interval in seconds, MEC is the current message epoch count, and ED is the published emission delay of the LORSTA sending this message.

Table of Alamanac Message Sub-types

Almanac Message Sub-Type 0: Reference Station List					
Part	**Description**	**# Bits**	**Bit Assignment (absolute)**	**Range**	**Explanation**
	LORSTA ID	8	8…15	[0,255]	Loran Station Identification Code
	Reference Station 1 ID	10	16…25	[0,1023]	Reference Station Identification Code: (see table for Reference Station Codes)
	Reference Station 2 ID	10	26…35	[0,1023]	Reference Station Identification Code: (see table for Reference Station Codes)
	Status	2	36,37	[0,3]	Code indicating status of Station: **00** = off air **01** = legacy **10** = LDC testing **11** = LDC operational
	Control Type	1	38	{0,1}	Flag indicating control used for station: 0 = SAM control, 1 = TOT control
	Blank/TBD	6	39…44	undefined	undefined

Almanac Message Sub-Type 1: Reference Station Latitude					
Part	**Description**	**# Bits**	**Bit Assignment (absolute)**	**Range**	**Explanation**
	Reference Station 1 ID	10	8…17	[0,1023]	Reference Station Identification Code: (see table for Reference Station Codes)
	Reference Station Latitude	26	18…43	[-90,+90]	Latitude of Reference Station (2.68e-6 degree/0.3 meter resolution
	Blank/TBD	1	44	undefined	undefined

Almanac Message Sub-Type 2: Reference Station Longitude					
Part	**Description**	**# Bits**	**Bit Assignment (absolute)**	**Range**	**Explanation**
	Reference Station 1 ID	10	8…17	[0,1023]	Reference Station Identification Code: (see table for Reference Station Codes)
	Reference Station Longitude	26	18…43	[-180,+180]	Longitude of Reference Station (5.36e-6 degree/0.6 meter resolution)
	Blank/TBD	1	44	undefined	undefined

Almanac Message Sub-Type 3: Reference Station Correction List (1-3)					
Part	**Description**	**# Bits**	**Bit Assignment (absolute)**	**Range**	**Explanation**
	Reference Station 1 ID	10	8…17	[0,1023]	Reference Station Identification Code (see table for Reference Station Codes)
	Signal ID # 1	8	18…25	[0,255]	Signal #1 Identification Code: An 8-bit code indicating the LORSTA being monitored by the reference site. The first five bits are described below. _*The last 3 bits are the same as listed under Message Type 15, station identification*_: **00000** = 5930 **00001** = 5980 **00010** = 5990 **00011** = 7270 **00100** = 7960 **00101** = 7980 **00110** = 8290 **00111** = 8970 **01000** = 9610 **01001** = 9940 **01010** = 9960 **01011** = 9990 **01100 ...11111** = unassigned e.g.: 00101100 = 7980Y (LORSTA Jupiter, FL)
	Signal ID # 2	8	26…33	[0,255]	Signal #2 Identification Code (same as above)
	Signal ID # 3	8	34…41	[0,255]	Signal #3 Identification Code (same as above)
	Blank/TBD	3	42…44	undefined	undefined

Almanac Message Sub-Type 4: Reference Station Correction List (4-6)					
Part	**Description**	**# Bits**	**Bit Assignment (absolute)**	**Range**	**Explanation**
	Reference Station ID	10	8…17	[0,1023]	Reference Station Identification Code (see table for Reference Station Codes)
	Signal ID # 4	8	18…25	[0,255]	Signal #4 Identification Code (see entry for Almanac message sub-type 3)
	Signal ID # 5	8	26…33	[0,255]	Signal #5 Identification Code (see entry for Almanac message sub-type 3)
	Signal ID # 6	8	34…41	[0,255]	Signal #6 Identification Code (see entry for Almanac message sub-type 3)
	Blank/TBD	3	42…44	undefined	undefined

Almanac Message Sub-Type 5: Reference Station Correction List (7-9)					
Part	**Description**	**# Bits**	**Bit Assignment (absolute)**	**Range**	**Explanation**
	Reference Station ID	10	8…17	[0,1023]	Reference Station Identification Code (see table for Reference Station Codes)
	Signal ID # 7	8	18…25	[0,255]	Signal #7 Identification Code (see entry for Almanac message sub-type 3)
	Signal ID # 8	8	26…33	[0,255]	Signal #8 Identification Code (see entry for Almanac message sub-type 3)
	Signal ID # 9	8	34…41	[0,255]	Signal #9 Identification Code (see entry for Almanac message sub-type 3)
	Blank/TBD	3	42…44	undefined	undefined

Almanac Message Sub-Type 6: Reference Station Correction List (10-12)					
Part	**Description**	**# Bi ts**	**Bit Assignment (absolute)**	**Range**	**Explanation**
	Reference Station ID	10	8…17	[0,1023]	Reference Station Identification Code (see table for Reference Station Codes)
	Signal ID # 10	8	18…25	[0,255]	Signal #10 Identification Code (see entry for Almanac message sub-type 3)
	Signal ID # 11	8	26…33	[0,255]	Signal #11 Identification Code (see entry for Almanac message sub-type 3)
	Signal ID # 12	8	34…41	[0,255]	Signal #12 Identification Code (see entry for Almanac message sub-type 3)
	Blank/TBD	3	42…44	undefined	undefined

Almanac Message Sub-Type 7: Nominal ASF Values (1-3)					
Part	**Description**	**# Bi ts**	**Bit Assignment (absolute)**	**Range**	**Explanation**
	Reference Station ID	10	8…17	[0,1023]	Reference Station Identification Code (see table for Reference Station Codes)
	Signal ID # 1 Nominal ASF Value	9	18…25	[0,255]	Signal #1 Nominal ASF Value
	Signal ID # 2 Nominal ASF Value	9	26…33	[0,255]	Signal #2 Nominal ASF Value
	Signal ID # 3 Nominal ASF Value	9	34…41	[0,255]	Signal #3 Nominal ASF Value
	Blank/TBD	3	42…44	undefined	undefined

Almanac Message Sub-Type 8: Nominal ASF Values (4-6)					
Part	**Description**	**# Bits**	**Bit Assignment (absolute)**	**Range**	**Explanation**
	Reference Station ID	10	8…17	[0,1023]	Reference Station Identification Code (see table for Reference Station Codes)
	Signal ID # 4 Nominal ASF Value	9	18…26	[0,25.6] µs	Signal #4 Nominal ASF Value
	Signal ID # 5 Nominal ASF Value	9	27…35	[0,25.6] µs	Signal #5 Nominal ASF Value
	Signal ID # 6 Nominal ASF Value	9	36…44	[0,25.6] µs	Signal #6 Nominal ASF Value

Almanac Message Sub-Type 9: Nominal ASF Values (7-9)					
Part	**Description**	**# Bits**	**Bit Assignment (absolute)**	**Range**	**Explanation**
	Reference Station ID	10	8…17	[0,1023]	Reference Station Identification Code (see table for Reference Station Codes)
	Signal ID # 7 Nominal ASF Value	9	18…26	[0,25.6] µs	Signal #7 Nominal ASF Value
	Signal ID # 8 Nominal ASF Value	9	27…35	[0,25.6] µs	Signal #8 Nominal ASF Value
	Signal ID # 9 Nominal ASF Value	9	36…44	[0,25.6] µs	Signal #9 Nominal ASF Value

Almanac Message Sub-Type 10: Nominal ASF Values (10-12)					
Part	**Description**	**# Bits**	**Bit Assignment (absolute)**	**Range**	**Explanation**
	Reference Station ID	10	8…17	[0,1023]	Reference Station Identification Code (see table for Reference Station Codes)
	Signal ID # 10 Nominal ASF Value	9	18…26	[0,25.6] µs	Signal #10 Nominal ASF Value
	Signal ID # 11 Nominal ASF Value	9	27…35	[0,25.6] µs	Signal #11 Nominal ASF Value
	Signal ID # 12 Nominal ASF Value	9	36…44	[0,25.6] µs	Signal #12 Nominal ASF Value

List of Differential Reference Station Codes

Number	Code	Description	City	State	Latitude	Longitude
0	0000000000	Loran Support Unit	Wildwood	NJ	n/a	n/a
1	0000000001	DOT Volpe Center	Cambridge	MA	n/a	n/a
2	0000000010	PCMS Sandy Hook	Sandy Hook	NJ	n/a	n/a
3	0000000011	US Naval Observatory	Washington	DC	n/a	n/a
4	0000000100	USCG Station Point Allerton	Hull	MA	n/a	n/a
5	0000000101	US Coast Guard Academy	New London	CT	n/a	n/a
6	0000000110	University of Rhode Island	Kingston	RI	n/a	n/a
7	0000000111	US Naval Research Laboratory	Washington	DC	n/a	n/a
8-1022	0000001000…1111111110	unassigned				
1023	1111111111	No Station/Do not use	n/a	n/a	n/a	n/a

Note: Differential Reference Station Codes numbered from 0 to 31 (0000000000 to 0000011111) are for testing purposes only. DO NOT use the information provided from these stations for navigation.